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Even simple forms of social learning rely on intention attribution in marmoset monkeys (*Callithrix jacchus*)

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Abstract

Intention attribution guides the cognitively most demanding forms of social learning, such as imitation, thereby scaffolding cumulative cultural evolution, but is not thought to be necessary for more basic forms of social learning. Here we present evidence that in marmoset monkeys even most basic forms of social learning such as enhancement depend on intention attribution. Marmosets perceived the behavior of a conspecific and a conspecific-like robot, but not that of a moving black box, as goal-directed. Their subsequent choice behavior was shaped by social facilitation and stimulus enhancement, that is very simple forms of social learning, but only when exposed to the conspecific and robot, which they previously had perceived as intentional agents. We discuss the implications of this finding for contemporary debates about social learning, including emulation learning and ghost control studies, the necessity of goal-directed copying for cumulative cultural evolution and the limits of current classification systems of social learning for the evolution social and asocial learning.

Key words: stimulus enhancement, goal-attribution, social learning processes, common marmosets (*Callithrix jacchus*)

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Social learning is an important means for the acquisition of information and skills, and underlies the cultural evolution seen in humans (Henrich & McElreath, 2003; van Schaik & Burkart, 2011). Since it encompasses all forms of learning that are influenced by observation of, or interaction with, another animal or its products (Heyes, 1994), it can take many different forms, as acknowledged by various classificatory systems (e.g. Byrne & Russon, 1998; Call & Carpenter, 2002; Heyes, 1994; Want & Harris, 2002; Whiten & Ham, 1992; Whiten, Horner, Litchfield, & Marshall-Pescini, 2004).

Categorizing forms of social learning potentially has various important advantages. It allows pinning down the social and ecological conditions that most strongly favor the evolution of (different forms of) social learning. It also enables comparative judgments about the cognitive complexity of a particular species showing a specific form of social learning. Most importantly perhaps, it can crucially contribute to our understanding of the evolution of social and asocial learning in different lineages, and have profound repercussions for theories addressing potential co-evolutionary processes between the two. The cultural intelligence hypothesis (van Schaik & Burkart, 2011), for example, assumes that because social learning is arguably more efficient than asocial learning, selection more readily favors social learning ability. If social learning ability involves cognitive mechanisms that also favor asocial learning, increased asocial learning ability and intelligence will ensue as a by-product.

The extent to which classifications of social learning actually provide these benefits, depends on the cognitive homogeneity of the categories, that is the degree to which a particular category reflects one uniform set of cognitive processes. Available classification systems of social learning do not necessarily satisfy this critical assumption, and may therefore be potentially misleading when used for evolutionary analyses related to cognitive complexity. For example, the two-action method tends to be used as an operational definition of imitation, but different species may reach the criterion of behavioral matching through different cognitive mechanisms (Byrne, 2005).

There are probably two main reasons for this cognitive heterogeneity of existing classifications. First, instances of social learning tend to be categorized based on outcomes rather than the (usually hidden) processes involved. Second, a wide range of criteria are used for classifying various forms of social learning. These include whether the behavior of a focal animal is influenced by another animal in general ways or whether copying occurs, and if so, which aspects of a behavior are copied (e.g. detailed actions vs global action sequences Byrne & Russon, 1998), whether the copied behavior is novel or not (Huber, 1998), or what sources of information are used (e.g. the goals, actions or results of behavior; Call & Carpenter, 2002). Other classificatory criteria that are used reflect primarily historic developments (e.g. the distinction between stimulus and local enhancement, for a review, see Heyes 1994). At the very least, the coexistence of multiple classificatory schemes and terminologies suggests the absence of consensus on the actual cognitive mechanisms involved.

For observational and imitational forms of social learning, efforts are underway to pin down the cognitive mechanism they are based on (Heyes, 2005), but this is not the case for the more simple forms of social learning, such as social facilitation or enhancement learning. In social facilitation (Zajonc, 1965), behavioral matching is thought to occur because the mere presence of a conspecific increases the general activity of a subject, which thus also increases the probability that it will show the target behavior compared to baseline. In enhancement learning, a conspecific interacting with a specific stimulus or being in a specific location increases the probability that the subject will also pay attention to the same stimulus or same location. Once its attention is focused on the same stimulus or location, individual learning may ensue. Thus, attentional processes and individual (e.g. stimulus-response) learning may well be sufficient for these forms of social learning (for a detailed analysis, see Heyes, 1994).

The aim of this study was to establish whether in common marmosets, social facilitation and enhancement effects do indeed follow the mechanistic pathway suggested by these accounts, or whether additional cognitive processes may play a role. In particular, we investigated whether intention attribution modulates the propensity to engage in these simple forms of social learning.

Throughout this paper, with intention attribution, we refer to early intention understandings of the sort shared by infants and nonhuman primates (reviewed in Wellman & Brandone, 2009), rather than a mature, human-like intention understanding based on a fully fledged Theory of Mind. In particular, we refer to the understanding of goal-directedness of actions as revealed in looking time studies modeled after the seminal study of Woodward 1998 (see

115 also Daum & Gredebäck, 2011, for a review of follow up studies with this
116 paradigm).

117 Based on the account of the simple forms of social learning outlined
118 above, intention attribution is not expected to play any role in social facilitation
119 and enhancement. Rather, it is thought to be required only for the cognitively
120 demanding forms of social learning, such as true imitation (Call & Carpenter,
121 2002; Tomasello, 1996, 1999; Tomasello, Kruger, & Ratner, 1993), where it
122 serves to regulate imitation at a meta-cognitive level through deliberate top-
123 down processes (Csibra & Gergely, 2007; Tomasello, 1996). However, just
124 because it is parsimonious to assume that social facilitation and enhancement
125 can result from a minimal set of cognitive mechanisms, this does not necessarily
126 mean that animals in the real world behave this way. Indeed, it seems more
127 efficient for animals only to attend to conspecifics that are engaged with their
128 environment in a goal-directed way, especially if these animals are gregarious
129 and thus nearly continuously exposed to conspecifics in proximity.

130 To assess intention attribution in the form of perceiving the goal-
131 directedness of behavior, we adopted and extended the habituation-
132 dishabituation looking paradigm originally developed by Woodward (1998) for
133 human infants. Looking paradigms have been successfully used with nonhuman
134 primates in both nonsocial (e.g. Cacchione & Krist, 2004; Santos, Seelig, &
135 Hauser, 2006) and social contexts (e.g. Hauser, 1998; Rochat, Serra, Fadiga, &
136 Gallese, 2008; Uller, 2004); see also Carey (2009) for a review).

137 The present goal attribution task consisted of a habituation and a test
138 phase (Figure 1). During the habituation phase, subjects observed an agent

repeatedly approaching and briefly interacting with the same of two equidistant objects (that is the target object). During the test phase, the position of the target objects had been switched. The agent now either continued to approach the target object as before and therefore had to take a new route, or, alternatively, performed exactly the same behavior as before in terms of its topography, that is walked along the same trajectory, which now, however, led to another object (i.e. the non-target object). Differential novelty reactions to the two test events (measured in terms of looking times) allows us to identify with regard to which dimension the subjects had encoded the habituation event. If during the habituation phase, the subject perceived the event with regard to the agent's goal-directedness, it would show a weaker novelty reaction during the test event where the agent continued to approach the same target object as before. Alternatively, if the individual encoded the habituation event predominantly with regard to the topography of the movement, the subject would react more strongly to a novel path and look longer if the agent changed its trajectory, but retained its original goal (Woodward, 1998). Longer looking times in the goal-violation event has thus been linked to a form of goal-attribution, which represents an early step in the development of a mature intention understanding. For an evaluation of alternative interpretations, see discussion.

Within the Woodward paradigm, we compared how the marmosets perceived the behavior towards objects of three different potential agents: a conspecific, a conspecific-like robot, and a black box. We hypothesized that the marmosets would attribute goal-directedness to the conspecific and perhaps, to a lesser extent, to the robot, but not to the black box.

163 To assess social facilitation and enhancement effects, the looking time
164 trials were immediately followed by free choice trials. This allowed us to assess
165 which of these three agents would induce social facilitation and enhancement
166 effects, and whether this was contingent on previous goal attribution to these
167 agents.
168 If social facilitation and enhancement effects only occur in those cases
169 where the behavior of the agent had beforehand been perceived as goal-directed,
170 intention attribution must play a role in simple forms of social learning in
171 marmosets. The role of intention attribution is particularly strong if such an
172 effect goes beyond a simple preference to preferentially pay attention to these
173 agents. If, alternatively, intention attribution does not play a role and a more
174 mechanistic pathway is at work, we expect a uniform influence of all agents on
175 the subjects' behavior during the free choice trials since the contingencies
176 between agents and objects were always identical.
177

178 **Methods**

179 **Subjects**

180 Thirty-three adult common marmoset monkeys (*Callithrix jacchus*) from
181 the Primate Station of the Anthropological Institute and Museum in Zurich
182 participated in the experiment. The animals were housed socially in pairs or
183 family groups ranging from 4-6 individuals in indoor cages (one or multiple units
184 of $4m^3$, according to group size); additional access to outdoor cages was available
185 during the warm season. The cages were equipped with various enrichment
186 devices and the animals were fed 3 times per day with fresh fruit, porridge and

187 insects; water was available ad libitum. For further details on housing conditions,
188 see Burkart & Heschl (2007).

189 We formed three experimental groups: for one, a conspecific acted as
190 agent, for the second a robot, and for the third a black box. An effect size analysis
191 of a pilot study (Burkart, 2004) suggested that 9-10 individuals are likely to be
192 sufficient to reveal an effect in this paradigm. In the conspecific condition, a
193 group member (breeding female) served as agent, and the remaining animals in
194 the two groups summed up to 9 subjects. In the robot group, we tested 10
195 subjects, and in the black box group, we first tested 10 subjects and decided to
196 add 4 additional ones in order to also be able to detect potentially weaker effects.
197 However, adding these four additional subjects did not alter the results.

198 In addition, 8 family groups (4-6 individuals per group) participated in
199 the object attractiveness tests conducted prior to the main experiment, which
200 served to establish that there was no a priori preference for one of the objects
201 used during the main experiment. These subjects did not participate in the main
202 experiment.

203 **Materials and Procedure**

204 *Perception of goal-directedness.* The stimuli (i.e. the agent approaching
205 and interacting with a target) were presented as video clips of 10 seconds rather
206 than as real-life events. This allowed us to standardize the timing of the stimuli
207 to make sure that it was identical in all trials and all conditions. Importantly,
208 previous findings had shown that common marmosets can use social information
209 presented as video clips for social learning (Burkart, Strasser, & Foglia, 2009).

The conspecific approached the target and quickly interacted with it (touching and sniffing); the robot and the black box approached the target and waggled in front of it. The black box was fixated over the robot and was thus moved by it, to ascertain that the behavior of the robot and the black box were identical with regard to approach trajectories and kinematics, as well as the waggling movement. An additional black cloth along the bottom boarders made sure that the legs of the robot were not visible.

The subjects were tested in an experimental cage consisting of three compartments, one with the video screen, an observation compartment from which the subjects could watch the video, and a waiting compartment where the animal stayed between trials (Figure 2). Each trial started with the subject waiting in the waiting compartment. As soon as the subject was relaxed and showed no sign of distress, such as vocalizations or piloerection, the experimenter opened the guillotine door to the observation compartment from outside, and the video clip started. The behavior of the subject was videotaped from outside, and after the trial was over (end of the 10-sec video clip), the door opened again and the animal could go back to the waiting compartment until the next trial started. We presented the marmosets with three habituation trials and two test trials, and recorded the duration the subjects attended to the stimulus sequences afterwards from the videos. The order of test trial type (old goal vs. old path) and the object serving as target object for the agents were counterbalanced between subjects, and the objects used were equally attractive (see below) and equidistant to the agent in the video clips, and also to the subjects during the free choice trials.

The day prior to testing, subjects were already presented with the habituation clips until they had watched 30% of the habituation clip during at least three trials, in order to make sure that they really had seen the event on the habituation video. Only subjects that passed this pre-criterion in no more than three days would proceed to the main test; five individuals did not proceed to the main test. The procedure of these pre-trials was the same as during the main test. The videos from this pre-habituation phase were analyzed in the evening of the same day. The day after a subject reached this criterion, the experiment started.

Social learning. Immediately after the last test trial, we ran free choice trials to investigate whether the subjects would copy the object choice of the agent. The video screen showed a still white frame, and while the subject was waiting in the preparatory compartment, the two real objects were placed in the observation compartment in front of the screen. Next, the door to the observation compartment opened again and the subject could enter it and interact with the objects, but it also had the option to simply leave the test area. If the monkeys entered the test compartment, we recorded which object they interacted with, and for how long.

Pretest: Object Attractiveness. In order to guarantee that subjects had no intrinsic preference for one of the two objects used as targets in the experiment, we conducted object attractiveness tests prior to the main experiment. We used 8 objects of similar size and material, but of different colour and shape. These objects were first presented in a randomized order to 8 groups of common marmosets that did not participate in the main experiment. We recorded the

latency until each object was first approached as well as the interaction duration and calculated the mean value for each object across groups. Based on this value, we composed 2 pairs of similarly attractive objects. These pairs did not differ significantly with regard to approach latencies and interaction durations (Pair 1: t_6 = -0.90, P=0.856 for the interaction time and t_7= -1.095, P=0.31 for the latency; pair 2: t_6=0.505, P=0.631 for the interaction time and t_7=0.115, P=0.912 for the latency). Finally, the objects were presented in pairs to the 8 groups. For pair 1, half of the groups first approached one object, the other half the other object. For pair 2, 5 groups first approached one object, and three the other one. We used pair 1 for all the experiments, and randomized which of the two objects served as target object across the subjects.

Data Coding and Reliabilities

All tests were video-recorded and analyzed with INTERACT software V8.0. from MANGOLD GmbH. An individual was coded as watching the screen if (i) its head was oriented towards the screen and (ii) it was not focusing on an entity other than the screen. Because common marmosets have conspicuous white tufts around their ears, coding their head orientation is straightforward. Focusing was defined as head- and eye orientation towards a given entity, often followed by approach behavior and exploration. The most common entities the animals focused on included the location where a front paw would be placed for the next step or small pieces of the test compartment such as screws or bolts it went to explore. Thus, whether such entities were focused on or not could most often be verified by subsequent behavior. All trials, including habituation trials, were

analyzed by two independent raters (rater 1 and rater 2), who were blind with regard to the experimental condition. An additional rater (rater 3) coded all test trials, also blind with regard to the experimental condition. The second, but not the third rater was trained by rater 1 to apply the above criteria in at least three video clips from the habituation phase. Inter-rater agreements as well as the correlation between the data are presented in table 1. All video clips are available on request.

Results

Intention attribution

The monkeys in all three groups showed a significant habituation effect over the three habituation trials (repeated-measures ANOVA: habituation trial (within): $F(2,60)=36.9$, $p<0.001$, weakest post-hoc comparison: hab1 vs. hab2: $t=2.194$, $p=0.056$; group(between) and (hab)x(group) interaction: ns.). In the test trials, the individuals looked longer at the goal violation in the conspecific and in the robot group but not in the black box group; in the black box group individuals looked longer at the trajectory violation (Figure 3, right hand side, repeated measures ANOVA: test (within): $F(1,30)=6.325$, $p=0.017$, group(between): ns, (test)x(group): $F(2,30)=8.924$, $p=0.001$). Thus, the subjects perceived the behavior of the conspecific (effect size $\eta_d^2=0.694$) and to a lesser extent of the robot ($\eta_d^2=0.399$), but not the behavior of the black box, according to its underlying intentional structure. We re-ran the analyses of the main effects (repeated measures ANOVA; within: test [congruent vs. incongruent], between: group [conspecific vs. robot vs. black box, see main text]) with the data from the

second and third rater. We obtained the same result as with the data from rater 1 (Table 2).

To rule out that differential outcomes in social learning (see below) simply result from attentional biases, we compared whether the subjects paid more attention to conspecifics and maybe the robot than the black box, during the first habituation trials. In this neutral condition, they did not pay differential attention to the conspecifc, the robot and the black box (ANOVA: $F(2,30)=0.254$, $p=0.777$, first bars in Figure 3; differences in looking time range between 2.14 % [conspecific vs robot] and 6.59% [conspecific vs black box]). Likewise, there is no difference for the second (ANOVA: $F(2,30)=0.068$, $p=0.934$; differences in looking time range between 0.92 % [robot vs black box] and 3.12% [conspecific vs robot]) and third habituation trials (ANOVA: $F(2,30)=2.261$, $p=0.122$; differences in looking time range between 0.23 % [robot vs black box] and 9.9 % [conspecific vs robot]). Thus, there was no a priori tendency in the subjects to pay more attention to the conspecific or the robot compared to the black box that could explain the social learning outcome.

Social learning

The free choice trials after the habituation-dishabituation experiment revealed the readiness of the marmosets to copy the agent's goal. If the subjects would be more ready to enter the middle compartment and interact with any of the objects, and would do so for a longer amount of time, this would be consistent with a social facilitation effect (Zajonc, 1965). If in addition, the subjects would more readily approach the target object first (i.e. the agent's goal)

and interact with the target object longer compared to the non-target object, this would be consistent with a stimulus enhancement effect (Whiten & Ham, 1992).

In the conspecific group, all animals entered the middle compartment, 88 % did so in the robot group, and in the black box group 71 %. The total interaction time with any of the objects was longest in the conspecific group, intermediate in the robot group and shortest in the black box group (one-way ANOVA: $F(2,30)=9.77$, $p=0.001$, for post-hoc significance levels see Figure 4a). This indicates that social facilitation was most strongly induced by the conspecific, to a lesser extent by the robot and even less in the black box condition (effect size Cohen's d: Conspecific vs Robot: $d=0.97$, Conspecific vs Black Box: $d=1.5$, Robot vs Black Box: $d=1.08$).

From those individuals who entered the experimental compartment, 89% approached the target object first (Binomial test: $p=0.039$) in the conspecific group, 78% did so in the robot group (n.s.) and 50%, exactly the random expectation, did so in the black box group. Animals in the conspecific and the robot groups interacted significantly longer with the target object than with the non-target object (repeated measures ANOVA: target(within): $F(1,30)=24.4$, $p<0.001$, group(between): $F(2,30)=9.591$, $p=0.001$, (target)x(group) interaction: $F(2,30)=8.25$, $p=0.001$, for post-hoc significance levels see Figure 4b). Thus, stimulus enhancement was induced by the conspecific (effect size $\eta_d^2=0.6$) and the robot ($\eta_d^2=0.65$), but not by the black box ($\eta_d^2=0.002$).

The same pattern of correspondence between goal attribution and social learning was present at the individual level across all conditions. With regard to first approaches, 77 % of individuals who looked longer in the incongruent test

event first approached the target object, compared to 46 % of individuals who looked longer at the congruent test event ($\chi^2(1) = 3.3$, $p = .069$). With regard to exploration time, 94 % of individuals who looked longer in the incongruent test event explored the target object for a longer amount of time, compared to 46 % of individuals who looked longer at the congruent test event ($\chi^2(1) = 8.66$, $p = .003$),

Discussion

Social facilitation and stimulus enhancement effects in marmosets were only induced by agents whose behavior had been perceived as goal-directed. This was the case when a conspecific or a robot, but not when a black box approached and interacted with a target object. Indeed, the social facilitation and enhancement effects were strongest after exposure to the conspecific, who was also perceived most consistently as an intentional agent by the subjects. This suggests that facilitation and enhancement effects are not purely mechanistically regulated by associative mechanisms, because these mechanisms should have been triggered by the black box as well which produced exactly the same contingencies and behaviors as the other two agents. These mechanisms seem thus not sufficient to explain the facilitation and enhancement effects in marmosets, but rather be supplemented by intention attribution.

Intention attribution or low-level explanation?

The marmosets in the conspecific and robot condition looked longer when the agent's behavior was inconsistent with regard to its previous *goal* than when it was inconsistent with superficial features (the topography) of its previous *behavior* (i.e., its path). Following the reasoning of Woodward and

colleagues (see also Carey, 2009 for a review), this indicates that they perceived the previous behavior (the habituation event) in terms of its underlying intentional structure, rather than in terms of its physical structure. Thus, the marmosets represented the agent's behavior as goal directed and could recruit these representations to make more complex inferences, including predictions about the agent's future behavior. In humans, such an early understanding of goal directedness later develops into a more mature understanding of intentionality (Wellman & Brandone, 2009).

Some have questioned whether longer looking at inconsistent goal behavior indicates sensitivity to goal directedness, or if more simple explanations are possible (for a review, see Carey, 2009). First, subjects may form an expectation merely based on the statistical regularities of the habituation event (i.e. a hand grasps for a specific object), in the absence of any perception of goal directedness. Thus, Tomasello and colleagues (2005) have argued that rather than perceiving the goal directedness of the agent, the subjects expect people to reach for the same object again and again. Vaish and Woodward (2005) argue that this is unlikely because infants do not show this looking pattern in the case of inanimate agents, which excludes any explanation referring to pure statistical regularities. Likewise, such an explanation can be excluded for the marmosets, because even though the contingencies were the same for all entities that served as potential agents, the monkeys did not react to the goal-violation by the black box.

Identifying the cues necessary to trigger these looking patterns in the marmosets requires additional experimentation. So far, we can exclude

biological motion, proposed by Rochat et al. (2005) because the robot moved non-biologically in the same way as the black box, and eye-like stimuli because the robot had no eye spots. Nevertheless, agent features do play a role, as evidenced by the fact that the black box did not elicit goal attribution in the marmosets. This may suggest that marmosets seem not to represent only the action itself, but rather the agent-action combination, as goal-directed, contrary to Gergely & Csibra's proposal for the intentional stance of human infants (Csibra, Gergely, Biro, Koos, & Brockbank, 1999; Gergely, Nadasdy, Csibra, & Biro, 1995). Furthermore, in humans, there is some indication that the range of stimuli to which intention is attributed is broadened during ontogeny (e.g. while six month-olds fail to react to the goal directedness of moving boxes (Kamewari, Kato, Kanda, Ishiguro, & Hiraki, 2005), 9 month-olds (Csibra, et al., 1999) and adults attribute intentionality even to geometric figures: Heider & Simmel, 1944). However, the role of the specific task used has not been disentangled sufficiently so far, and it may well be that rather than age alone, the format of the task defines which agent stimuli are required for goal-attribution. Thus, even for humans the key stimuli have not yet been identified.

A second alternative explanation to differential looking pattern in the Woodward task is that it measures an expectation derived from everyday experience. However, people do not normally reach for the same object repeatedly (Vaish & Woodward 2005). The same is true for marmosets, and even more so for the robot, which the subjects in the present study had never observed to behave in a goal-directed way beforehand. Indeed, Vaish & Woodward (2005) point out that their task was designed for novelty detection,

rather than as a violation-of-expectation test, and longer looking in one test event over the other reflects which dimension of the event predominantly influenced the perception of the habituation event (i.e. the superficial, physical, vs the intentional structure of the behavior).

According to Carey (2009), a richer interpretation of looking time results is supported if the knowledge representations revealed in looking time paradigms can also be shown to have an inferential role for action production. An infant study (Hamlin, Hallinan, & Woodward, 2007) revealed that 7 month-olds copy the choice between two objects after having seen how an adult acted upon one of these objects. However, they only did so for those actions that have been shown to elicit differential looking patterns in other studies with the Woodward Paradigm. In the present study, an inferential role of the attribution of goal-directedness as expressed in looking times for direct action has also been shown in the same subjects, thus favoring a rich interpretation of the looking time results.

Finally, the knowledge apparent in looking time studies is often not recruited for guiding action in infants (Matter Mandler, 2004). It may thus constitute a transitional developmental stage that is necessary for the development of action-guiding knowledge, but not functional in itself. Such an explanation is intuitive for human infants who, at the time when they demonstrate knowledge in perception, but not action based tasks, are still completely depending on their mothers and performing correct actions is not yet vital for them. In the present study, this explanation is unlikely (see also Cacchione & Burkart, in rev.), (i) because we tested fully mature subjects for

whom knowledge which is never translated into action is unlikely to be of adaptive value (Gomez, 2005) and (ii) because a broad body of evidence suggests that nonhuman primates have a simple understanding of others' behaviors as intentional (Call, 2007; Rosati, Hare, & Santos, 2010). Indeed, macaques have been shown to respond when a human experimenter reaches for a goal in an "irrational" way (Rochat et al. 2008), just like 9 and 12 month-olds children do, which represents even a further step in the development towards a mature understanding of intention (Tomasello et al. 2005). A recent review by Wellman and Brandone (2009) shows that early intention understandings shared by children and nonhuman primates predict children's later theory of mind. In sum, the marmosets' looking pattern in the present study most likely reflects a simple intentional understanding in terms of the goal-directedness of an action, similar to the one shown by 6 month-old children.

Intention attribution and social learning

Our results suggest that the regulation of the so-called simple forms of social learning (social facilitation and stimulus enhancement) is cognitively less mechanistic than is theoretically possible and often assumed. In stimulus enhancement, the attention of a subject is drawn to a specific stimulus by another individual who interacts with that stimulus, and subsequent individual (asocial) learning is more likely to result in convergent behavior compared to an asocial situation. Since all agents approached the target object with identical contingencies, the attention of the subjects should have been drawn equally to the target object in all three conditions. This scenario would thus predict a uniform influence of the agents' behavior on the subject's own choice. This was

not the case. Indeed, we suggest that the variation in the strength of social learning was related to variable goal-attribution because we can exclude the following two most plausible alternatives.

First, the stronger social learning effects in the conspecific condition than in the robot condition and than in the black box condition could have arisen because of an intrinsic preference to pay more attention to a conspecific or a conspecific-like entity. Because this would automatically draw the attention more to the target object as well, this could sufficiently explain the pattern of observed facilitation and enhancement effects. However, we empirically addressed this possibility by comparing how much attention the animals paid to the different agents in a neutral condition but found no difference. Hence, the animals were not simply more attracted to the conspecific or, to a lesser extent, to the robot compared to the black box. The animals rather must have processed the events differently: those with the robot or conspecifc as agent predominantly with regard to goal-directedness, and that with the black box with regard to its goal directedness. The results from the free choice trials suggest that only the first way of processing leads to social learning.

Second, it could be argued that there is something about the interaction of a conspecific with an object that serves as a releasing cue for stimulus enhancement (e.g. the association of a grasping hand with an object) but has nothing to do with the perception of goal-directedness. However, because the robot and the black box moved with exactly the same kinematics and interacted in exactly the same way with the object (waggling in front of it), this explanation cannot account for the result that the subjects reacted to the goal violation by the

robot and learned socially from this. Thus, the most likely explanation for the pattern of results is that the conspecific and the robot were perceived as intentional agents and that this was crucial for the release of stimulus enhancement in the subjects. Whether the reported social facilitation effect was also driven by the perception of goal directedness cannot yet be decided at this point since we cannot rule out that the mere presence, rather than the activity, of a conspecific would have had the same effect.

We now turn to the question how the attribution of goal-directedness could promote social learning. When ascribing a role to intentional understanding in social learning, this influence tends to be construed as a deliberate top-down process at a meta-cognitive level (e.g. Csibra & Gergely, 2007; Tomasello, 1996). However, a growing body of evidence reports that in humans the attribution of mental states, including intentions, is not only regulating behavior at a deliberate or even meta-cognitive level, but also happens more automatically and may influence very basic social behaviors, such as gaze following and even perception (Teufel, Fletcher, & Davis, 2010). Since the first possibility may require advanced cognitive functioning available only to very few species, and since the habituation-dishabituation paradigm measures implicit rather than explicit understanding of goal-directedness (see Carey, 2009 for an in-depth discussion into what kind of knowledge system looking time studies tap), a non-deliberate influence is more likely.

Luo and Baillargeon (2005) found that in infants, differential looking patterns only emerge if during the habituation trials both potential goal objects were present during habituation. This may suggest that infants interpret the

behavior of the agent as reflecting its preference between the two objects, rather than merely as a reflection of the agent's goal to reach of a particular object (see also Carry 2009). Our results suggest the same may be the case in the marmosets, and we therefore predict that like in infants, differential looking patterns should not emerge if only one target object was present during habituation.

The perception of goal-directedness may serve as a cue at the first stage of enhancement learning, when the attention of the subject is drawn to the specific stimulus or location. However, it might also influence subsequent individual exploration, since not only the first choice between the objects was contingent on the previous perception of goal-directedness, but also the interaction duration. In other words, the subjects also became more persistent in exploring an object after perceiving an agent as having approached this object in a goal-directed way, which is not expected if this second stage is pure individual learning. Thus, the perception of goal directedness seems to signal where an individual should increase explorative activity. This is likely to be very functional because it limits the detailed exploration response to situations where conspecifics are engaged in a meaningful activity rather than merely present or moving about.

Implications for contemporary debates about social learning

The results of this study also have implications for other contemporary debates about social learning. First, they may help to explain failures to demonstrate emulation learning with ghost control studies. In emulation

545 learning, the subject learns about the affordances in the environment rather than
546 about the behaviors and their underlying intentions (Hopper, 2010). To
547 distinguish emulation from imitation, ghost control experiments are conducted,
548 in which the agent is removed to identify the effects on the observer of the
549 demonstration per se, particularly in highly cultural species such as chimpanzees
550 (Hopper, 2010). If a goal-directedness interpretation is crucial for a broad range
551 of social learning processes in primates, failures in ghost control studies need
552 not indicate the absence of imitation. Instead, they most likely imply that the
553 subjects in such studies react to the absence of goal-directedness, since by
554 removing the agent from the demonstration, not only the topography of the
555 action is removed, but also all agency cues, thereby strongly reducing the
556 salience of the demonstration.

557 Second, our findings may improve our insight into the role of intention
558 attribution for the origin of human cultures. Some nonhuman animals show
559 simple cultural systems in which individual innovations spread through the
560 population via social learning (Whiten & van Schaik, 2007). Nevertheless, human
561 cultures remain unique with regard to the accumulation of cultural elements
562 whose cognitive complexity far exceeds an individual's inventive potential
563 (cumulative cultural evolution, Tennie, Call, & Tomasello, 2009). The most
564 prominent attempts to explain this idiosyncrasy attribute a key role to distinct
565 social learning processes (reviewed in Caldwell & Millen, 2009; Hill, 2010).
566 Specifically, they argue that humans, unlike apes, rely on truly imitational forms
567 of social learning which involve the reproduction of both the specific action and
568 the goal of the observed behavior, and thus require a concept of intentional agent

(Tomasello, 1999; Tomasello, et al., 1993). Our results show that the modulation of social learning processes by intention attribution is neither unique to humans, nor restricted to cognitively demanding forms of social learning, and thus unlikely to be the key factor for cumulative cultural evolution since it is already present in nonhuman primates.

Finally, our results may question the adequacy of existing classification systems that are based on the outcome of social learning rather than on the cognitive mechanisms involved. It is conceivable that intention attribution is not involved in all cases of social facilitation or enhancement reported in the literature. For example, red-footed tortoises have been reported to show stimulus or local enhancement learning (Wilkinson, Kuenstner, Mueller, & Huber, 2010). Having a solitary lifestyle, they are not expected to be sensitive to the goal-directedness of others' behaviors, which, in addition, would influence their social learning. This suggests that forms of social learning that are traditionally captured under the same label may be much more heterogeneous with regard to the cognitive processes involved than is currently acknowledged. Further studies that empirically map which cognitive mechanisms are involved in which social learning phenomena would crucially contribute to validating the classification systems currently used.

The availability of valid classification systems of social learning is particularly relevant for evolutionary approaches to understanding the emergence of social and asocial learning, and cognition in general (van Schaik & Burkart, 2011). A future extension of the knowledge about the cognitive mechanics of social learning might reveal that social learning processes as they

593 are traditionally classified based on outcomes (Heyes, 1994) do not directly map
594 onto classifications that would emerge if the same instance of social learning
595 were categorized according to the cognitive processes involved.
596

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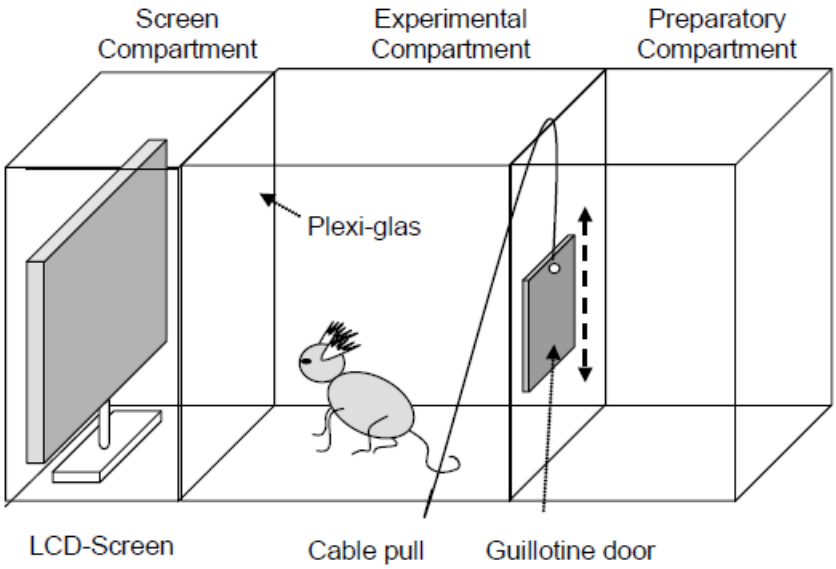
Figure 1: Goal-attribution task. During the habituation phase, the subjects are repeatedly presented a videoclip showing an agent approaching one of two target objects, until they habituate to it and lose interest. During the test phase, the position of the objects is reversed. In one test event, the agent's behaviour conforms to the superficial topography of his previous behaviour, that is its trajectory (test *goal violation*); in the other test event, the agent's behaviour conforms to the intentional structure of its previous behaviour and approaches the same object as before, but along a new trajectory (test *no goal violation*). If the animals perceived the behaviour during the habituation phase according to its goal-directedness, they are predicted to look longer in the goal violation test event.



742

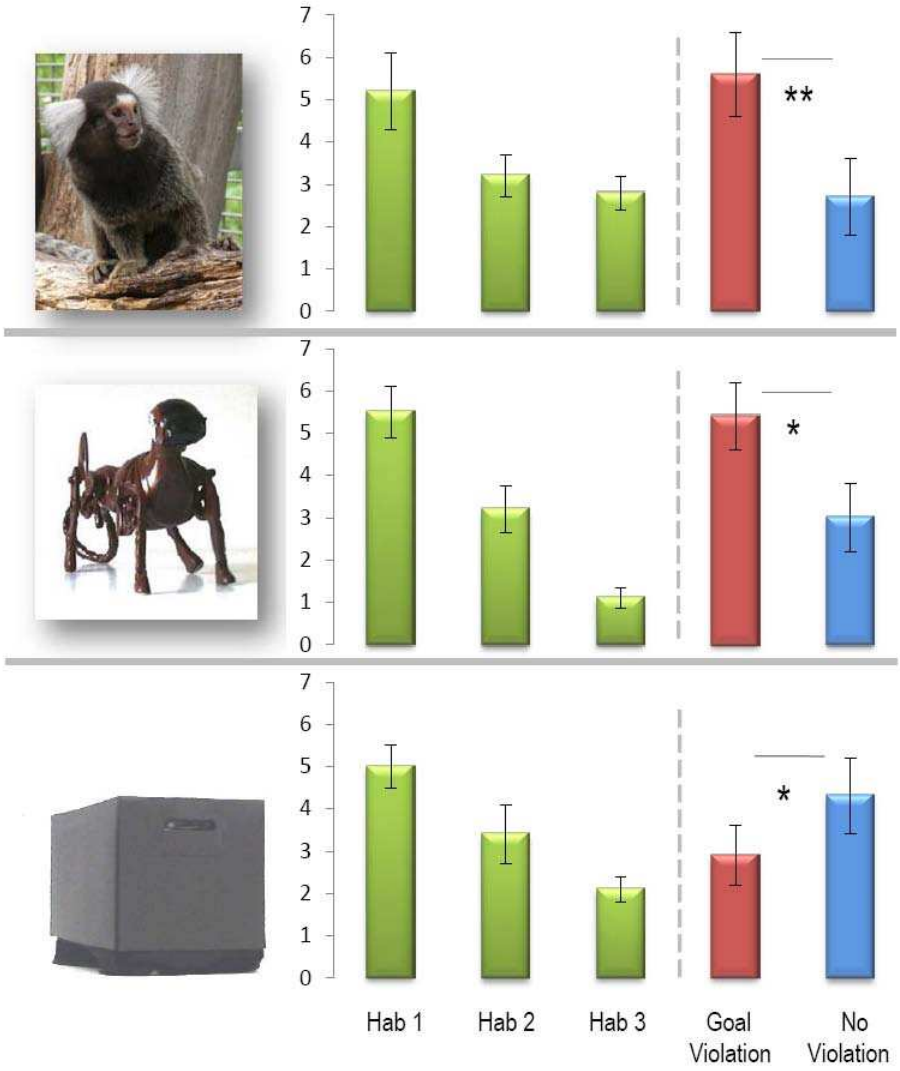
743 **Figure 2**. The experiment was conducted in an enclosure consisting of three

744 compartments, one for the LCD screen, an experimental compartment, and a

745 preparatory or waiting compartment where the subjects were waiting between

746 trials.

747



748

749 **Figure 3**. Left hand side: Agents used in the video clips for the three
750 experimental groups (a conspecific, a conspecific-like robot, and a black box).
751 Right hand side: Looking durations (s ± S.E.M.) in the goal-attribution tasks. In all
752 conditions, looking times continuously decrease during habituation trials and
753 recover during test trials. In the test trials, goal violation led to a stronger
754 reaction in the conspecific and the robot group. Thus, the conspecific (upper
755 row) and the robot (middle row) are perceived as intentional agents, but not the
756 black box. *(=p<0.05) and **(=p<0.01) indicate post-hoc significance levels for
757 the test events.

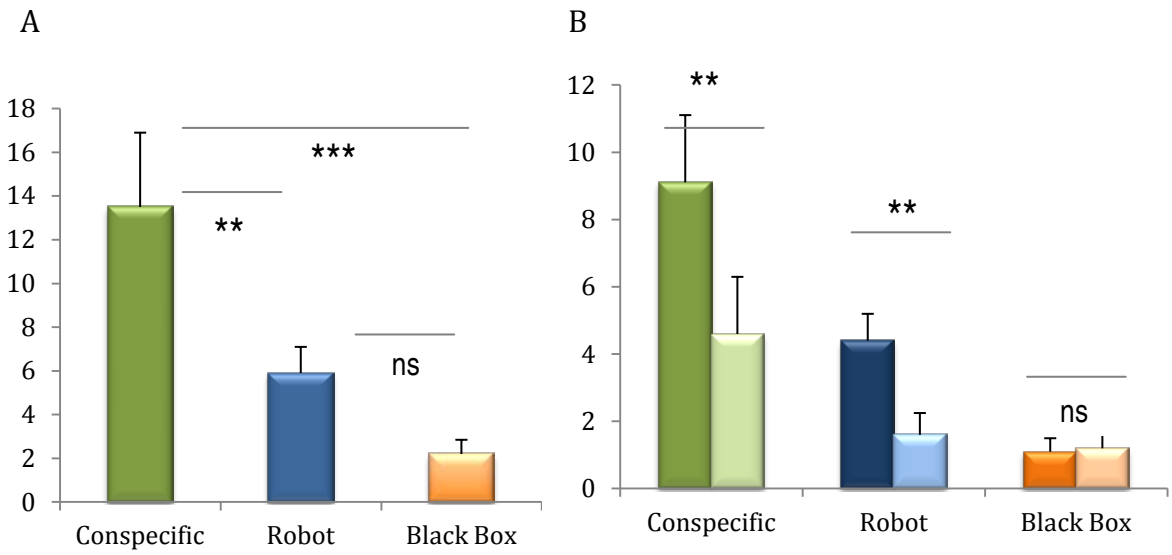


Figure 4. Social learning results. A: Social facilitation. Interaction duration with both objects (s ± S.E.M.). Observing a conspecific approaching a target object induced stronger social facilitation than observing a robot and observing a black box did. B: Stimulus enhancement. Duration of interaction (s ± S.E.M.) with the target (dark bars) vs. the non-target (light bars) object. Stimulus enhancement was induced by the conspecific and the robot, but not by the black box. **(=$p<0.01$) and ***(=$p<0.001$) indicate post-hoc significance levels.

779 **Table 1**: Inter-rater agreements and correlations based on looking duration per
780 trial. $: agreements between rater1 and 2 were also calculated at the frame level
781 (1frame=0.04sec). Values for rater 1 and 2 include the three habituation trials
782 and the test trials, whereas the additional rater 3 rated test trials only.
783 N=number of trials, ***: p<0.001.
784

	Conspecific	***Robot***	***Box***	***Total***
% agreement				
$ Rater1-Rater2	98.08%	95.38%	94.98%	96.01%
Rater1-Rater2	N=45, 98.60%	N=50, 99.37%	N=70, 99.15%	N=165, 99.06%
Rater1-Rater3	N=18, 96.8%	N=20, 95.34%	N=28, 94.73%	N=66, 95.48%
Rater2-Rater3	N=18, 96.8%	N=20, 95.8%	N=28, 94.9%	N=66, 95.68%
correlations				
Rater1-Rater2	N=45, r^2=0.992***	N=50, r^2=0.988***	N=70, r^2=0.998***	N=165, r^2=0.996***
Rater1-Rater3	N=18, r^2=0.962***	N=20, r^2=0.974***	N=28, r^2=0.970***	N=66, r^2=0.97***
Rater2-Rater3	N=18, r^2=0.964***	N=20, r^2=0.974***	N=28, r^2=0.970***	N=66, r^2=0.97***

785
786

787

788 **Table 2**: Comparison between raters. The data of the test trials was analyzed separately for
789 the data set from rater1, rater2 and rater3. The pattern of results is the same in all three
790 cases.

791

	Group (between)	***Test (within)***	***Test x Group***
Sum of squares			
Rater 1	16.1	19.3	54.4
Rater 2	15.94	18.8	52.6
Rater 3	9.26	13.22	37.9
F-values			
Rater 1	0.74	6.3	8.9
Rater 2	0.79	5.95	8.3
Rater 3	0.433	4.72	6.8
p-values			
Rater 1	0.487	0.017	0.001
Rater 2	0.496	0.021	0.001
Rater 3	0.652	0.038	0.004

792